RESEARCH INTO METHODS OF IMPROVING BLAST FURNACE COKE QUALITY AT B.H.P. NEWCASTLE, AUSTRALIA WITH SPECIAL REFERENCE TO THE EFFECT OF BENTONITE

J. A. Gregory

The Broken Hill Proprietary Company, Ltd.
Newcastle, N. S. W., Australia

The high ash, medium to high volatile coking coals available in the vicinity of the Iron and Steel works at Newcastle(1) yield a very poor quality blast furnace coke by most world standards. This factor, combined with rapid expansion of the Company's production facilities, has emphasised the need for extensive investigation of methods of improving the quality of the coke made from these coals.

Fine grinding of the coal charged to the ovens at Newcastle has been of recognised practical benefit, and in fact, common plant practice for some thirty five or more years,(2,3,4) and the grind specification over this period has generally varied between the equivalent of 50% to 70% minus 18 mesh B.S.S. which is very fine by most standards. However, with the expansion of the company's research activities and the installation of pilot scale research equipment(5), it was considered desirable to investigate the effect of coal grind and the use of additives in more detail.

An early stage of this research comprised experimental and full scale oven tests on the effect of coal grind on coke strength. In addition, many series of tests comparing the effect of various additives previously investigated, such as char made from non-caking coals, were carried out over a range of coal charge sizings. In the course of the above investigations, observations made in relation to the effect on coke strength of Wyoming bentonite and the bentonitic clayshales associated with the unwashed coals resulted in the concentration of a good deal of research effort on mineral matter associated with both northern and southern New South Wales coal seams.

Considerable detailed research on the effect of additives such as char, coke-breeze, iron ore, and limestone has been carried out which fully confirms the advantages of char addition in comparison with other recognised methods of coke strength improvement. However, it is not intended to describe this work in any detail here, save to compare the coke strength data with that obtained in the investigation of finer grinding and bentonite.

EXPERIMENTAL OVEN TESTS ON UNWASHED COALS

In November 1956, as part of a long range program of improving the quality of blast furnace coke used at the Newcastle steelworks, investigations of the coking characteristics of the northern coal seams and variations between the same seams at our several collieries were commenced. These experimental oven tests were carried out prior to the installation of the Pilot Scale Coal and Coke Research Laboratory(5), and consequently, close control of such charge variables as ash content and coal grind was not always possible. A large number of oven tests were of necessity carried out in an attempt to clarify the effect of the many variables encountered.

The results of a series of earlier experimental oven tests are shown in figure 1, in which the trend in relationship between coke strength indices and coal grind are shown.

It can be seen that increasing the fineness of grind of the coal charge has resulted in an increase in the strength of the coke as measured by the A.S.T.M. stability, hardness, and shatter indices. These results indicated the possibility of increasing the stability of the coke from less than 20 to over 30 by increasing the fineness of grind. Coke of 30 stability has previously only been obtained on a production basis at Newcastle by adding approximately 25% lower volatile southern N.S.W. strongly coking coal to the northern blends. The incorporation of this southern coal, although resulting in improved blast furnace operation, has generally been considered an expensive answer to the problem of improving Newcastle blast furnace coke quality. The results obtained by finer grinding suggested therefore, an alternative method to the use of southern coal. However, it was also realised that there existed a number of practical problems in relation to achieving and handling on a production scale grinds finer than 70% minus 18 mesh.

FULL SCALE FINE GRIND TESTS ON UNWASHED COALS

In February to April 1958, ten series of fine grind trials were carried out in the full scale ovens at Newcastle. The bulk of these tests were carried out using Lambton Colliery, Victoria Tunnel Seam, Burwood Colliery, Borehole Seam and Burwood Dudley Seam coals in the unwashed condition. Facilities were not available to carry out tests on individual seams after washing, but it was possible to test the effect of coal grind on the then current northern blend ex the washery and the final test in this series was conducted on such a sample washed to 14% ash. The overall result of the effect of coal grind on coke strength for this series of tests, on coals ranging from 13% to 21% ash content, is shown in figure 2. Calculation showed that these full scale oven tests gave a close correlation with the results obtained in the experimental oven on northern coals at a similar ash level.

Promising though these results were in regard to the effectiveness of finer grinding, the discovery of the beneficial effect of small percentages of bentonite and bentonitic shales in northern coals[5,6], provided reason for caution in assessing the effectiveness of fine grinding. In addition, during the tests, considerable difficulty was experienced in handling the very finely ground coal charges, which is a further important consideration in regard to finer grinding.

A closer examination of the results of the full scale fine grind tests on Victoria Tunnel, Dudley and Borehole seam coals showed that there were at least three variables which could be contributing to the increase in coke strength, the other two being ash content and coal seam variation. Fine grinding had been most effective with the high ash Dudley seam coal, and least effective with the lower ash Borehole seam coal.

In addition, later investigations showed that of the coal seams tested, the Dudley and Victoria Tunnel seams containing bentonitic clay-shales gave the best results on finer grinding, whereas the Borehole seam containing relatively little bentonite gave the least improvement.

Because of the number of variables that could be contributing to the effectiveness of fine grinding, it was clear that the problem of significantly and economically improving northern blast furnace coke quality by finer grinding was more complex than originally thought.

EXPERIMENTAL AND FULL SCALE OVEN TESTS ON WASHED COALS.

(a) Experimental Oven Fine Grind Tests

In 1959 full scale wet washing of the fine coals on Deister tables replaced dry tables and the ash in the washed coal to the commercial ovens was reduced from 15% to 11%. Blast furnace operation benefited considerably from the reduction of 4% in coal ash, however, there was a fall-off in coke strength. In spite of the fact that the 4% reduction in ash gave several points increase in coke A.S.T.M. hardness index, the A.S.T.M. shatter and stability were reduced somewhat and there was a marked increase in the amount of spongy coke produced.

The opportunity was taken to carry out experimental oven fine grind tests on these current washed coals of 11% ash. Two series of tests were carried out, each on a ten ton sample from the full scale washery. As anticipated, finer grinding was somewhat less effective with these washed coals. However, it was also found that in the experimental oven, these washed coals gave considerably better quality coke at coarse coal grinds than did the full scale ovens. Although the reasons for this improvement were obscure, it was clear that reasonably strong coke could be produced in the experimental oven at (by our standards), relatively coarse coal grinds of the order of 40% to 50% minus 18 mesh B.S.S.

(b) Full Scale Oven Tests Comparing Fine Grind, Char and Bentonite

Since mid 1956, some 850 experimental oven charges of approximately 850 lbs each had been coked in investigation of various measures taken to improve coke quality, and it had been concluded that the most promising avenues of further investigation were finer grinding, 5% char addition and 1% Bentonite addition. These three methods although presenting their own individual problems as regards full scale application, were considerably more effective in the experimental oven that say, iron ore, coke breeze or limestone additions.

Therefore, a number of full scale oven charges were prepared at the Works Research Laboratory (as described in more detail in the next section), in order to confirm the results obtained in the experimental oven. The results of these tests are given in table I.

TABLE I.

Full Scale Oven Tests Comparing Fine Grind, Char and Bentonite Addition.

Description of Charge	Coal Grind %-18B.S.S.	A.S.T.M. Coke Physical Test Data 1½ Shatter	1"Stability	¼"Hardness
8 Control Tests (Range)	40/55	68/74	16/24	68/71
Mixed Charge (No additions)	48	71	19	68
1% Bentonite	48	76	34	72
5% Char	44	82	38	68
Fine Grind	65	77	29	73

From Table I it can be seen that the experimental oven findings were confirmed. Although 1% bentonite addition was not the most effective, it was decided to carry out further tests with smaller percentages of bentonite. If sufficiently effective in improving coke strength, less than 1% bentonite addition would offer a simple method of carrying out full scale blast furnace trials with stronger coke to determine the value of the latter in relation to operation of our Newcastle blast furnaces.

EXPERIMENTAL AND FULL SCALE OVEN TESTS ON THE EFFECT OF BENTONITE ON COKE QUALITY

The discovery of the beneficial effect of a small percentage of bentonite on Newcastle coke strength was made in May 1958 in the newly installed Pilot Scale Coal and Coke Research Laboratory (figure 3), and became the first major research program using this equipment. As has been reported elsewhere[5,6,7], a considerable number of experimental oven tests (figure 4) were carried out in investigation of the effect of both Wyoming bentonite and the bentonitic shales associated with the Newcastle coal seams.

From these experimental oven tests, it was shown that, although variable in properties, the local bentonitic clayshales associated with the coal seams approached Wyoming bentonite in their capacity to affect an improvement in the strength of Newcastle coke. It was also shown that 1% bentonite added to the lower volatile strongly coking southern N.S.W. coals had a marked detrimental effect on coke quality.

When the opportunity arose to carry out full scale oven tests to confirm these effects, it was decided to concentrate initially on the use of Wyoming bentonite in order to keep the test variables to a minimum.

(a) Full Scale Oven Tests Prepared at the Works Research Laboratory in a Spiral Mixer

The first full scale oven test with 1% of Wyoming bentonite added to the coal was carried out in March 1960 and resulted in such a marked improvement in coke quality that attention was concentrated on the addition of only 1/4% to 1/2% of bentonite. These tests were carried out by withdrawing full oven charges from the battery bunkers using the spare charging machine. After charging the necessary control tests, a full oven charge was transferred to a lorry at ground level and taken to the pilot plant laboratory where the dry bentonite was carefully blended using a spiral ribbon mixer. The mixed charge was bagged and returned to the battery where the four hundred bags (approx.) were hoisted to the top of the battery and emptied into the cannisters of the charger. The results of the physical tests carried out in triplicate on the cokes produced in this manner are given in Table 2.

TABLE 2.

FULL SCALE OVEN TESTS WITH BENTONITE

Description of Charge:	Coal Grind % -18B.S.S.	A.S.T.M. Coke Physical Test Data 1½" Shatter:	1" Stability:	¼" Hardness:
6 Control Tests (Range)	40/55	69/74	16/20	68/70
1% Bentonite	48	76	34	72
½% Bentonite	54	77	37	71
¼% Bentonite	41	77	31	70

From table 2 it can be seen that a marked improvement in coke strength has resulted from addition of either $\frac{1}{4}$%, $\frac{1}{2}$% or 1% bentonite. The run-of-oven coke produced at Newcastle from the current washed coal of approx. 11% ash and 39% volatile matter (d.a.f.) besides giving poor coke strength, of the order of that shown for the control tests in the tables, contains an excessive amount of sponge coke. The addition of even a $\frac{1}{4}$% bentonite resulted in virtually complete elimination of this sponge and a less fingery coke product. Figures 5 and 6 illustrate the difference in appearance of the cokes produced with and without bentonite addition. These photos are of a single bag of each coke selected at random. Even in a casual examination of the cokes, there could be little hesitation in selecting the one containing bentonite.

(b) Full Scale Oven Tests Prepared at Coke Oven Hammer Mills with no Separate Mixing.

The next series of full scale oven tests were aimed at determining the simplest practical method of adding the bentonite to the coal in anticipation of a full scale test in the blast furnaces over an extended period. It was decided to test the effectiveness of the hammer mills alone in mixing the bentonite with the coal. A small hopper and vibrating feeder were set up to feed bentonite on to the stream of coal feeding into the hammer mills. For the tests, sufficient coal was run through the mill to fill a sample bin (3 oven charges). Two or three control charges without bentonite were prepared and charged, followed by three charges with $\frac{1}{4}$% to $\frac{1}{2}$% dry bentonite powder added to the coal stream.

The results of the first test series carried out by adding the fine dry bentonite at the hammer mill are given in table 3.

TABLE 3:

FULL SCALE OVEN TESTS ADDING $\frac{1}{4}$% BENTONITE AT THE HAMMER MILLS

Description of Charge:	A.S.T.M. Coke Physical Test Data: 1$\frac{1}{2}$" Shatter:	1" Stability:	$\frac{1}{4}$" Hardness:
Control	65	13	72
"	64	15	73
$\frac{1}{4}$% Dry Bent.	73	24	71
"	67	24	72
"	68	24	72

From the results of the above test, it was apparent that the coal used was of poorer quality than normal as reflected in the physical tests on the control charges. The test was repeated using the same technique of adding the bentonite at both $\frac{1}{4}$% and $\frac{1}{2}$% levels of addition. The results of these test series are given in table 4.

TABLE 4

FULL SCALE OVEN TESTS ADDING ¼% AND ½% BENTONITE AT THE HAMMER MILLS

Description Of Charge:	A.S.T.M. Coke Physical Test Data: 1½ Shatter:	1" Stability:	¼" Hardness:
Control Tests	65	17	72
" "	63	16	70
" "	67	16	73
¼%Dry Bent.	75	27	71
" "	70	30	75
" "	73	24	72
Control Tests	65	17	72
" "	65	18	74
" "	63	17	71
½%Dry Bent.	70	29	71
" "	75	30	70
" "	67	30	71

These full scale oven tests (table 4) confirmed that ¼% to ½% bentonite could be added to the stream of coal entering the hammer mills with results comparable to those obtained by careful mixing.

DISCUSSION

Based on the results obtained in experimental and full scale oven tests, it is planned to carry out trials in the coke ovens and blast furnaces at Newcastle over an extended period. The Newcastle plant has a nominal capacity of 300 tons/hour of washed coal. We will aim at ⅓% dry bentonite addition to the coal stream entering the hammer mills. That is, we will be adding 1 ton/hour of ash forming material to the coal, and it must be admitted that the benefits obtained need to be sufficient to justify such an unusual precedent.

However, there is no doubt that bentonite markedly improves Newcastle blast furnace coke quality. We therefore, have the opportunity of answering the age old question concerning the benefits of coke quality on blast furnace operation, by a simple practical process. Undoubtedly, valuable information will be obtained.

Our aim as regards the coke strength in the blast furnace trial will be to produce a sponge free coke of the order of 75 shatter (1½"), 30 stability and 70 hardness. Whether we can achieve this specification will depend to a large extent on the degree of control we can exercise over the uniformity of addition of the bentonite to the coal stream entering the hammer mills, and on the coal grind obtained in the mills. In most of the full scale oven tests carried out to date, the coal grind has been below 50% minus 18 mesh B.S.S. which is generally considered coarse for our types of coal. We know from experience that the beneficial effects of finer coal grind and bentonite addition can be combined to give a stronger coke. During the trial therefore, we will aim to maintain the coal grind above 50% minus 18 mesh (the minimum acceptable figure under normal conditions), which should ensure our achieving the desired coke strength indices.

There are many questions in our minds regarding the possible significance of the effect of bentonite on coke strength which can only be answered by further research and the proposed full scale trial.

On the fundamental side, there is the question of the mechanism by which bentonite affects an improvement in the quality of the high volatile northern N.S.W. coals. At the moment, our thinking favours the theory that the ion-exchange capacity of the bentonite favourably effects the stability of the bonding constituents in these coals. On the other hand, we have the contrast in effect on the lower volatile southern N.S.W. coals which in a limited investigation, have shown a marked deterioration in coke strength with bentonite addition.

The soft clayshales associated with the unwashed northern N.S.W. coals have been shown to possess bentonitic properties to varying degrees, some to a marked extent. The addition of 1% of bentonitic clayshale removed from the unwashed coal before washing and re-added to the washed coal has also resulted in a marked increase in coke strength. However, it is apparent that the beneficial properties of these clayshales are lost during coal washing, because after washing to 11% ash, these coals in practice, should contain sufficient of this clayshale to give an increase in coke strength. That an increase in coke strength has not resulted in practice is attributed to loss of ion-exchange capacity of the clays during washing. This aspect offers a further interesting field of research.

There remains something to be learnt regarding the best method of adding bentonite to the coal. A limited amount of work has been carried out on the addition of the bentonite in slurry form in both water and oil. The bentonite can be dispersed readily in the oil used for bulk density control, but it was considered that in this form, the ion-exchange capacity might be lowered to such an extent by the oil that the effect on the coke strength would be less marked. Results obtained to date with oil dispersion have been variable and further research is required on this point.

Water slurries of bentonite have given much the same order of improvement in coke strength as the dry bentonite additions. However, although by no means proven conclusively as yet, it is our impression that the moisture content of the coal may play an important role in the effectiveness of the dry bentonite addition. That is, the coal charges with higher moisture seem to give stronger coke with the dry bentonite addition. However, this issue is somewhat clouded by other variables at the moment.

On the production side, we hope to obtain an answer to the question of the relative merits of cokes of 30 stability and 15 stability in the blast furnaces at Newcastle. If the trial is successful from the point of view of control and coke strength and little effect is shown on blast furnace operation and production, then we will need to revise our assessments of what constitutes blast furnace coke quality. On the other hand, should blast furnace operation benefit significantly from the use of the bentonite coke, we will be a further step forward in the common goal of improving blast furnace productivity by the use of tailor made raw materials.

ACKNOWLEDGEMENTS

The author is indebted to the Directors and Management of the Broken Hill Pty. Co. Ltd., for permission to publish this paper.

The passage of this laboratory conception through the pilot plant stage to a full scale production trial required the cooperation and extra effort of many colleagues together with constructive criticism at each step in the process. Although it is not practical to single out all of those who participated, the author is especially indebted to the Chief Works Research Officer, Mr.D.O.Morris and Works Research Officer, Mr.D.H.Felton who have been closely associated with this and every phase of our coal and coke research program.

REFERENCES

1. Standards Association of Australia - "The Coal Resources of Australia" Power Survey Report No.3 - 1955, p.29.

2. Butler K. - "Coal, Coke and By-Products - Their Treatment at Newcastle". B.H.P.Review, Vol.2, No.11, 28th Jan. 1925, p.5.

3. McLennan, I.M.- "Washed Coal as Applied to Metallurgical Practice" Bureau of Steel Manufacturers, Annual Meeting, 3rd Sept. 1940, p.40.

4. Norgard, J.D. & Brook, W.H. - "Coal Utilization in Modern Steelworks Practice". Preprint Aust.Inst.Mining & Metallurgy, May 1947, p.10.

5. Gregory, J.A. - "Pilot Plant Research into Methods of Improving Blast Furnace Coke Quality". B.H.P.Technical Bulletin, Vol.3, No.1, March 1959, p.23.

6. Gregory, J.A. - "The Effect of Mineral Matter in Coal on the Physical Strength of Blast Furnace Coke-Pilot Oven Test Results with 1% of Bentonite or Bentonitic Shale Added to the Coal Charge", The Institute of Fuel (Australian Branch) 1959, Symposium on "Australian Fuels and Their Utilization", Paper B11.

7. Felton, D.H. & Gregory, J.A. - "Pilot Plant Research into Methods of Improving Blast Furnace Coke Quality - A Summary of Experimental Oven Data". B.H.P.Technical Bulletin, Vol.4, No.2 1960.

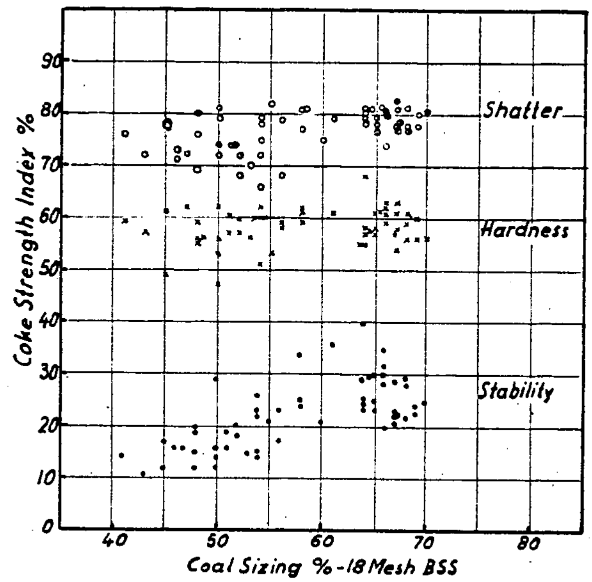

Fig. 1 - Experimental Oven Fine Grind Tests on Unwashed Newcastle Coals

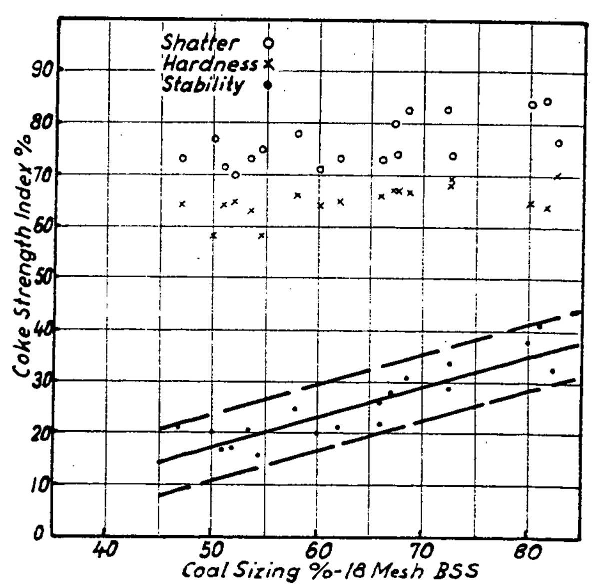

Fig. 2 - Full Scale Oven Fine Grind Tests on Unwashed Newcastle Coals

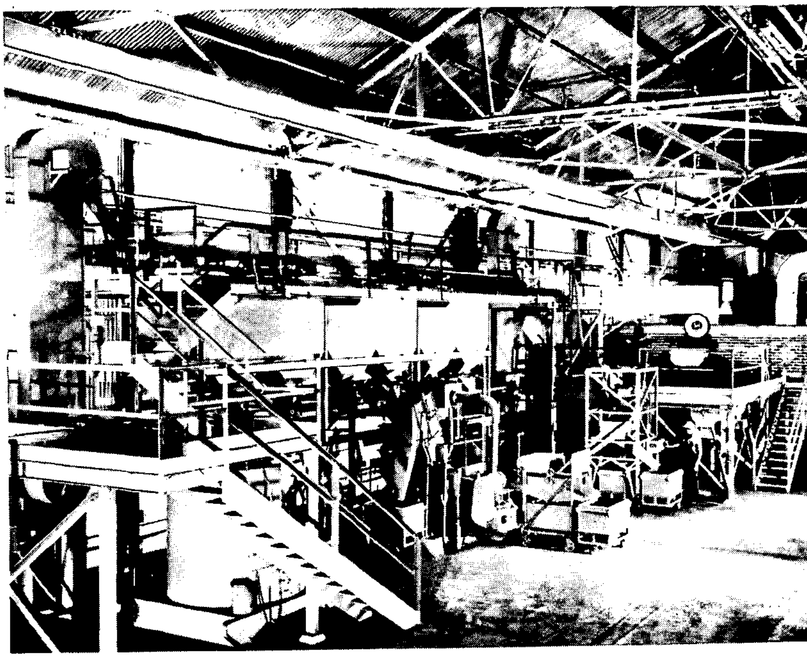

Fig. 3: - Section of the Pilot Scale Coal & Coke Research Laboratory.

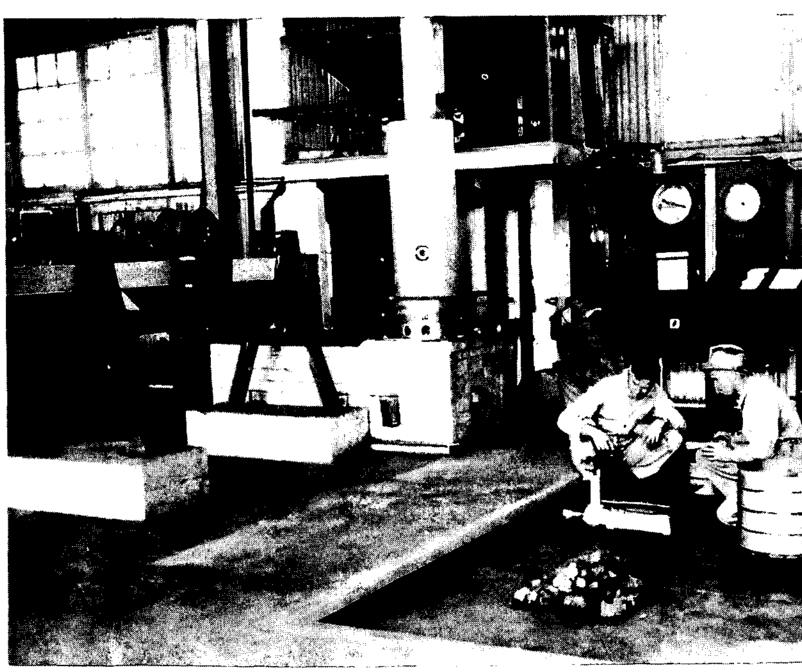

Fig. 4: - The Experimental Coke Oven.

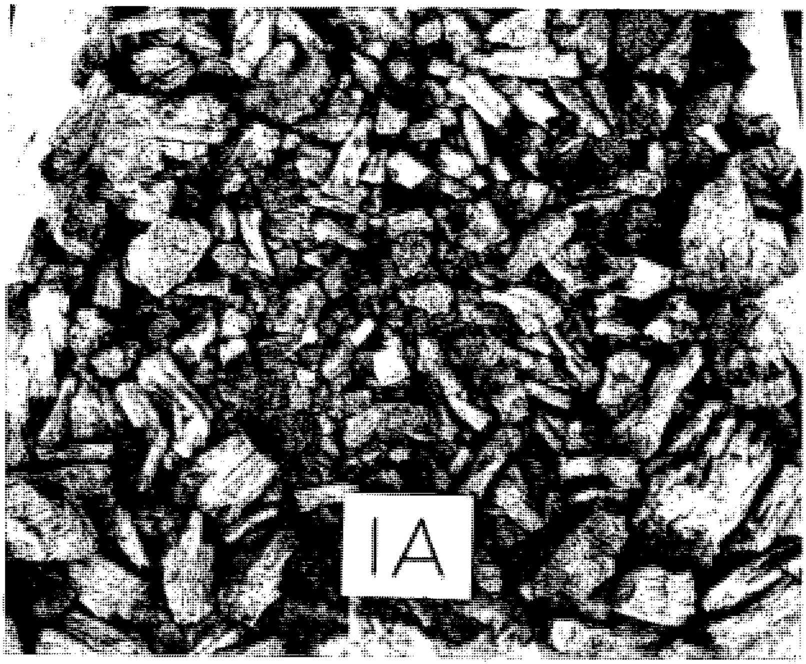

Fig. 5: - Control Test, Full Scale Oven, Typical Spongy Run of Oven Coke.

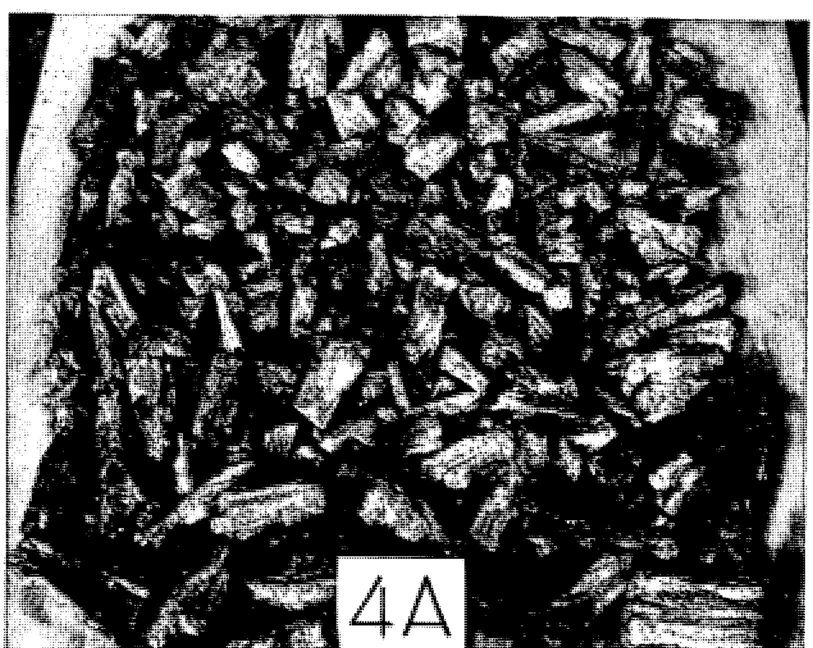

Fig. 6: - Full Scale Oven Test ½% Bentonite Addition.